ATLAS OF GOLD COMPOSITIONS FOR BRITISH COLUMBIA

Developing a New Tool for the Exploration Community

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1. INTRODUCTION

- Gold particles are commonly recovered during exploration but are not widely used as an indicator mineral.
- Gold particle geochemistry is a function of the source mineralization style and could be used to infer deposit type.
- We are building an "Atlas" of gold compositions in BC - a comprehensive geochemical database which characterizes gold from different source mineralization styles.
- The Atlas will be publically available, and provide a template against which new composition data can be compared.
- We will develop a machine learning approach to facilitate interrogation of new sample populations of gold particles against the Atlas database.
- The initial data base generated by the project will be progressively expanded as new data becomes available.
- New data from the project feeds into ongoing parallel studies of Cordilleran metallogeny[1]
- The new tool will be suitable for exploration projects of all sizes.

Projected completion of initial phase by Roundup 2022

2. USING THE ATLAS DATABASE

Detrital gold grains recovered during exploration

Geochemical Characterization

Identification of inclusions using SEM
Determination of alloy composition using EPMA
Trace element concentrations using LA-ICP-MS

Compare data against Atlas Database

Available at Geoscience BC

Manually

Correlation of new data with relevant information in Atlas Database

Machine Learning classification models

Automatically identify related populations within Atlas database

User's manual

Implications of Gold Characterization

Can the source style of mineralization of the sample population be identified?
Are the new samples comparable to others from the same area?
Does this extend the geographical range of known mineralization?

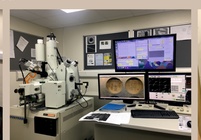
REFINE EXPLORATION TARGET

Identification of geological setting of *in situ* source based on characterization of populations of gold particles and gold particle distribution

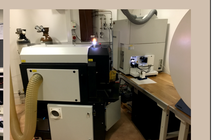
3. BUILDING THE ATLAS

Analytical Techniques Employed

SEM
Mineral inclusions



EPMA
Major elements in alloy



LA-ICP-MS
Trace elements in alloy

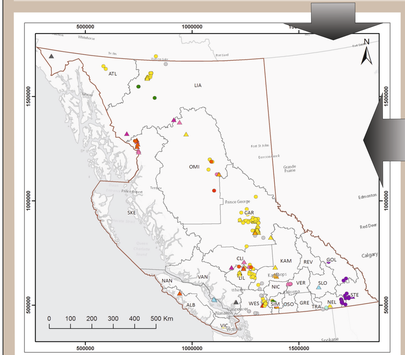
UoL Collection

Published alloy composition data for Au, Ag, Cu, Hg and Pd and inclusion mineralogy (EPMA, SEM)[2,3]
(68 localities, 3868 gold particles)
Trace elements (e.g. Cu, Hg, Pd, Sb, Pb, Bi, Te) (LA-ICP-MS)[4]
(25 localities, 884 gold particles)

UBC Collection

Legacy collection of UBC comprising published + unpublished compositional data for Au, Ag, Cu and Hg (EPMA)
(148 localities, 5364 gold particles)

Existing Data



Legend

Sample type: Hypogene, Detrital
Mineralization style: Orogenic, VMS, Skarn, Unknown; Porphyry: Alkalic, Calcalkalic; Epithermal: Low sulphidation, High sulphidation; Intrusion-related: Intrusion-related (inferred), Reduced intrusion-related gold, Ultramafic intrusion-related
Mineral districts: District boundary

ALB	Alberni	LIA	Liard	REV	Revelstoke
ATL	Atlin	LIL	Lillooet	SIM	Similkameen
CAR	Cariboo	NAN	Nanaimo	SKE	Skeena
CLI	Clinton	NEL	Nelson	SLO	Slocan
STE	Fort Steele	WST	New Westminster	TRA	Trail Creek
GOL	Golden	NIC	Nicola	VAN	Vancouver
GRE	Greenwood	OMI	Omineca	VER	Vernon
KAM	Kamloops	OSO	Osoyoos	VIC	Victoria

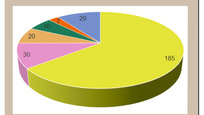
New Data

Mineral inclusion data from UBC legacy samples

Trace element data by LA-ICP-MS *(c 800particles)*

Alloy and inclusion data from new samples both collected and donated

Analyses of more particles from



Breakdown of entire sample set according to deposit type

Sample Localities and Deposit Types

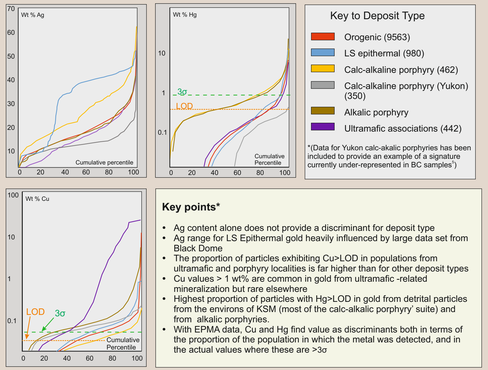
- 'Other' = intrusion related (18), Skarn, (4), HS epithermal (2), VMS (2). In addition the source style for a further 40 samples is unknown.
- Gold from two calc-alkalic localities near KSM is detrital, and may be derived from associated epithermal mineralization.

Projected size of initial database:
12509 PARTICLES from 353 LOCALITIES

4. PRELIMINARY DATA ANALYSIS

Alloy compositions by EPMA

Comparisons between deposit types according to Ag,Cu and Hg



Key to Deposit Type

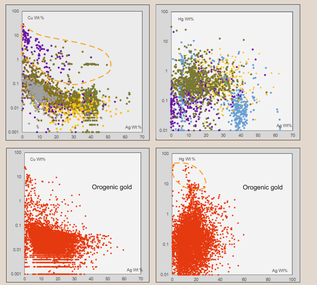
- Orogenic (9563)
- LS epithermal (980)
- Calc-alkaline porphyry (462)
- Calc-alkaline porphyry (Yukon) (350)
- Alkalic porphyry
- Ultramafic associations (442)

*(Data for Yukon calc-alkalic porphyries has been included to provide an example of a signature currently under-represented in BC samples[1])

Key points*

- Ag content alone does not provide a discriminant for deposit type
- Ag range for LS Epithermal gold heavily influenced by large data set from Black Dome
- The proportion of particles exhibiting Cu>LOD in populations from ultramafic and porphyry localities is far higher than for other deposit types
- Cu values > 1 wt% are common in gold from ultramafic -related mineralization but rare elsewhere
- Highest proportion of particles with Hg>LOD in gold from detrital particles from the environs of KSM (most of the calc-alkalic porphyry' suite) and from alkalic porphyries.
- With EPMA data, Cu and Hg find value as discriminants both in terms of the proportion of the population in which the metal was detected, and in the actual values where these are >3σ

Ag vs Cu, Ag vs Hg bivariate plots

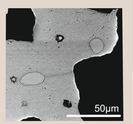


- Data for orogenic gold presented separately to more easily faciliate comparison with gold from other deposit types
- Most compositional fields show large degrees of overlap
- For Cu, Hg and Ag, gold analyses from the large majority of analyses lie within a continuum.
- Exceptions are the elevated Cu contents of gold associated with ultramafic deposits and some populations of orogenic gold containing elevated Hg (highlighted by dashed lines).

Mineral Inclusion Suites

Methodology

View of polished block, showing populations in rows of 5 particles



Example of inclusions revealed in polished section: Galena in gold particle from Black Dome, southern BC

Schematic representation of a sample population, showing a hypothetical scenario of inclusion abundance

Stages in generating radar plots

1. From observations using SEM, gain tally of particles containing each inclusion species.

2. Ascribe a metal score of 1 and a non metal score of 1 to each inclusion; e.g. for pyrite Fe=1, S=1, for chalcopyrite Fe=0.5, Cu=0.5, S=1 etc.

3. Score the inclusion population according to inclusion type and abundance.

4. For the metal diagram, express the proportion of each metal element on a log-scale radar diagram

5. Repeat for non metal elements

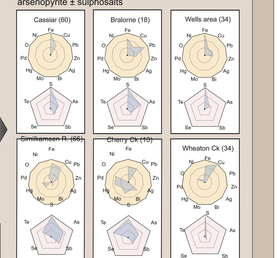
Numbers in parentheses on plots refer to number of inclusions in the

Summary of importance of inclusion data

1. Deposit-scale studies have shown inclusion signatures specific for gold from calc alkalic porphyries, alkalic porphyries and their epithermal expressions[1-3].
2. Inclusion signatures of gold from orogenic deposits are elementally and mineralogically more simple than those from magmatic hydrothermal systems, and conform to types defined by non metals.
3. Inclusion suites are the best single discriminant for deposit type, but not all samples provide sufficient data for characterization.

Examples of deposit type inclusion signatures

Orogenic gold: S-As±Sb, Fe+ base metals, corresponding to an inclusion suite commonly containing pyrite, chalcopyrite, galena, sphalerite, arsenopyrite ± sulphosalts



Gold from alkalic porphyry systems (Similkameen R. Cherry Ck (Afton): exhibits a distinctive Pd-Hg signature, plus a wider range of elements than gold form orogenic systems.
Gold associated with ultramafic lithologies: (Wheaton Ck): inclusion suite dominated by chalcocite and bornite

5. DEVELOPING APPROACHES TO INTERPRETATION OF DATABASES

This work is ongoing, and we present here the factors which have influenced our preliminary work, and those which will be taken into consideration in future.

Suitability of analytical data

Classical characterization of compositional features of populations of gold particles have combined alloy data measured by EPMA with Inclusion data gained from inspection using SEM. The data sets exhibit several features which are accommodated by manual data manipuation but which are challenging to translate to a generically applicable algorithm;
1. Ag is the only elements always detectable in Au alloy, but it is not an effective discriminant
2. Cu and Hg are clearly useful discriminants in some cases, but are often present at levels below LOD
3. Inclusions provide an excellent basis for characterization but are typically observed in only around 10% of polished sections. Consequently they are rare in many of the legacy samples because these were not collected with a view to generating inclusion suites.
4. Large data sets generated by LA-ICP-MS provide more discriminants for consideration whilst providing robust quantitative data regarding Cu and Hg.
5. The amount of LA-ICP-MS data to the study is relatively limited (c 800 particles) and does not currently include suitable sample sets of all deposit types.

Initial investigations into suitability of different methods of classification by machine learning

We have undertaken a pilot study using LA-ICP-MS gold alloy data relating to gold from orogenic, alkalic porphyry and LS epithermal settings. The elements of this study are shown in the flowsheet below.

Generating the data

Selection of data sets for analysis.
Cleaning data set prior to multivariate analysis

Selection of variables to act as discriminants

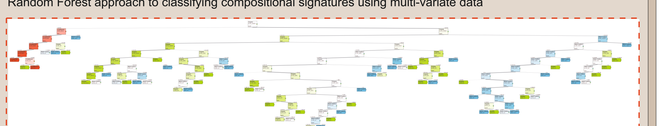
Identification of As, Au, Cd, Co, Cr, Cu, Fe, Hg, Pb, Pd, Te, V, W, and Zn

Application of machine learning

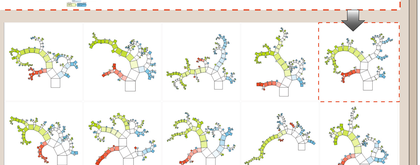
Application of kNN, SVM, Random Forest, Neural Network and Naive Bayes approaches

Identification of Random Forests as the approach most suited to the data set

Random Forest approach to classifying compositional signatures using multi-variate data



The figure above shows one of the ten decision trees generated during this pilot study. The collection of classification trees comprises the random forest. The elements near the top of the tree (Au, Cu, Hg) are the most significant discriminators with respect to deposit type (for this data set). White nodes are shared by more than one deposit type, and coloured nodes indicate singular deposit type. Darker colours indicate higher probabilities. Elemental ranges and breaks are recorded at the top of each node. The colour coding shows areas of the forest that relate to the LS epithermal gold data, (red) orogenic gold samples (green) and gold from alkalicic porphyry systems (blue). Visual assimilation of the data encapsulated in a single forest is challenging, and the problem is excacerbated when considering all trees in a study. The data may be represented by 'Pythagorian Forests' (right) in which heirarchical characterizations are represented efficiently.



Data outputs from the ten random forest classification trees depicted as pythagorean forests.

6. COMMENTARY

This project has assembled the largest data base of gold compositional data to be considered in a single study. It is clear that Alloy compositions from EPMA do not usually yield signatures diagnostic of deposit type, because Cu and Hg are often present in concentrations near their limit of detection, whereas data from LA-ICP-MS analysis and characterization of inclusion suites yield mineralogical characteristics capabale of underpinning a indicator mineral methodology. Our immediate challenges are to expand the data base of gold compositions obtained by LA-ICP-MS analyses and to develop a methodology to combine these data sets with inclusion data to establish robust training data for algorithm development.

Ongoing work within the project

- Incorporate LA-ICP-MS data describing gold compositions into the Atlas data base
- Complete outstanding analyses of sample sets according to availability of analytical facilities during Covid 19-related lockdown
- Investigate approaches to integration of data sets specific to gold, where important characteristics are present in only some of the particles within a population. This applies to both alloy components (e.g. Pd) and most importantly, to inclusions.
- Interrogate data sets of all alloy compositions and inclusion assemblages to identify the most robust training data set for comparison with new data sets.
- Creation of robust classification scheme, and accompanying workflow and user manual, to enable classification of newly collected microchemical data.
- Production of final report

Future research

- The final training data set can be applied immediately to consider the sources of placer gold in various localities where this is currently unclear.
- Compositional data at the trace and ultra trace level may be used to increase understanding of gold depositional models and they can illuminate fluid sources, for provide evidence of fluid-rock interaction.
- The approach developed here will be applied to compositional data sets of gold from Yukon and Alaska to provide an integrated resource for gold study thoroughout the N American Cordillera.

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Gone Planting